

The Nineteenth KEKB Accelerator Review Committee Report

March 3, 2014

Introduction

The Nineteenth KEKB Accelerator Review Committee meeting was held on March 3-5, 2014. The Committee welcomed Paolo Chiggiato (CERN) as a new member to replace Miguel Jimenez (CERN). Matt Poelker (JLab) was invited for this meeting for advice on the injector. Appendix A shows the present membership of the Committee. The following members of the Committee were unable to attend: Stuart Henderson, Kem Robinson. The meeting followed the standard format, with two days of oral presentations by the KEKB staff members, followed by discussion between the Committee members. The Agenda for the meeting is shown in Appendix B.

The amount of progress that has occurred in the year since the last review is truly impressive. As always, the high standard of the presentations impressed the Committee, particularly the new members. The Committee evaluated the present status of the project and prepared recommendations, which were presented to the KEKB staff members before the close of the meeting. The Committee wrote a draft report during the meeting that was then improved and finalized by e-mail among the Committee members. The report is available at <http://www-kekb.kek.jp/MAC/>.

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A) Executive Summary

Construction of SuperKEKB started in 2010, three and a half years ago. Since that time, an enormous amount of work has been completed. The KEKB ring components were removed from the tunnel and many are being refurbished and reinstalled. The new LER and HER ring components have largely been designed and most have been fabricated and installed. The vacuum chamber construction is well underway with the beam pipes being baked and coated with TiN in a brand new facility. The new pipes and cables were procured and are being installed. Eight new buildings have been built for utilities, and the cooling and electrical plants were reinforced. The RF accelerating system is being reconfigured to support higher beam currents. In parallel, the upgrade of the Linac is nearly complete to meet the new requirements for injection into SuperKEKB. A new positron Damping Ring has been designed, its tunnel constructed, and all of the components have been procured and installation is ongoing. All in all, the work needed for SuperKEKB and its injector are going very well. This progress is extremely impressive.

There remain significant challenges. The final interaction region is complex. The focusing that is required to produce the design luminosity is extremely strong and the associated optical lattice aberrations are difficult to correct. Many simulations are ongoing to find corrections for the ultimate machine configuration. The commissioning of the rings has three phases, each with more demanding accelerator and beam requirements. The machine optics design and construction for the initial SuperKEKB operations in Phase 1 has already been finalized and is on track. The magnets, vacuum chambers and support structures for the ultimate interaction region are well into design and many components prototyped. Half of the interaction region superconducting quadrupoles have been designed, prototyped and partially assembled. The backgrounds generated by the high current beams can have strong effects on the data collection and quality of the particle physics detector Belle II. Many simulation and shielding studies are ongoing, aiming at adequate background control. The beam lifetime will be short in SuperKEKB due to the luminosity lifetime, strong Touschek effect, and reduced dynamic aperture from the beam-beam effect in the nano-beam interaction region. A large effort is underway working on increasing the beam lifetime while maintaining the peak luminosity to reduce the detector backgrounds and relieve pressure on the injection system.

According to the original schedule, beam commissioning should start before the end of JFY14. However, the recent cuts in the JFY14 operating budget will push the start of Phase 1 beam commissioning to the middle of JFY15. If the reduction to operating funding persists into later years, it will have a strong negative impact on commissioning, peak luminosity, and delivered luminosity to Belle II.

Overall, the ARC Review Committee congratulates the accelerator team on very solid progress on construction of SuperKEKB and its injector and firmly expects that beam commissioning of the rings will start in 2015.

B) Recommendations: The Committee has made recommendations throughout the different sections below. Highlights of these recommendations are summarized here.

- 1) Despite the strong support of KEK management to increase staffing, including a few new junior hires and rehiring senior, experienced retired staff, shortage of qualified staff continues to be a risk to successful completion of the project, the commissioning and operations. The number and skills of the additional staff members going forward should be optimized for the commissioning and operations phases of the project.
- 2) Expand efforts to involve collaborators (e.g. from BINP, BNL, CERN, Cornell, IHEP, INFN, SLAC, other light sources and/or KEK-ATF) in the commissioning of all three SuperKEKB rings (damping ring, LER, HER).
- 3) While complete optics solutions exist for Phase I and Phase II, reaching the final luminosity in Phase III depends on solving a challenging set of interconnected beam dynamics problems. At this time, a complete overall solution has not been found. The Committee recommends that studies continue to optimize the luminosity.
- 4) The SuperKEKB/Belle II interaction region IR is extremely complex and the Committee recommends continued attention to the issues of the beam-beam interaction, beam lifetime, superconducting magnets, vacuum pressure, backgrounds, assembly, and machine detector interfaces.
- 5) With key components of the injector now installed and operational, significant effort should be devoted to achieving the necessary beam stability to support commissioning of new and critical downstream components.
- 6) Belle II and SuperKEKB management teams should jointly develop the run objectives and parameters for the early physics running in SuperKEKB Phase II commissioning by fall JFY2015.
- 7) Belle II and SuperKEKB control teams should determine soon the full list of control data that need to be shared between the two control systems and the electronic exchange mechanisms.
- 8) In order to complete the Damping Ring commissioning during a one-month period, a precise commissioning plan needs to be prepared with detailed procedures and decision trees and sufficient commissioning staff identified.

C) Findings and Comments

1) KEK Roadmap

The previous KEK roadmap from 2008 to 2012 was shown, indicating that most of the program items were completed or started as planned. The list included the JPARC upgrade program, enhanced KEKB/Belle program, LHC program, Photon Factory program, and general accelerator and technology programs. The upgrade of KEKB/Belle was an outcome of this roadmap.

The new KEK road map for 2013 through 2018 was finalized in May 2013 with similar high-level areas, but with different specific goals. It continues the strong program of JPARC upgrades aimed at reaching the initial goal of each scientific area and preparing for J-PARC science in 2020's. The completion and commissioning of SuperKEKB/Belle II is central to the program with a goal of completing the construction of the accelerator and detector facilities, and then to achieve the design luminosity performance on schedule and to initiate in-depth exploration of new physics. The LHC/ATLAS goal is to continually participate in the experiment and to take a proactive initiative in upgrade programs of both the accelerator and detector facilities. The ILC program has developed since the roadmap with a clearly enunciated proposal for KEK to play a central role in creating an international preparatory group, leading the effort on advanced R&D, the engineering design of the apparatus and facility, and the organizational design toward groundbreaking for the linear collider project to be hosted in Japan, within the framework of a global collaboration. KEK will continue to advance photon science by upgrading the Photon Factory (PF) and Photon Factory Advanced Ring (PF-AR); constructing and then operating the compact energy recovery linac (c-ERL) and will demonstrate the key technologies required for the ERL. KEK will then work toward construction of a 3 GeV ERL facility. KEK will also promote research that has the potential to significantly expand accelerator and detector technologies in the long term with a national and health focus. Recently, an additional program has been added to promote cooperation with industries and universities in Japan and abroad for accelerator based science.

Overall, this is a very strong program and matches well the various programs around the world.

2) Overview of Ring Construction Status and Schedule

The SuperKEKB construction implies massive upgrades of the LER and HER main rings, including many new magnets and power supplies, replacing beam pipes, with new ones containing an antechamber, reinforcing the RF system for doubled beam current, as well as adding a damping ring (DR) for positrons, and an upgrade of the injector linac.

Three phases of commissioning are foreseen as defined earlier. Phase 1 is without the final quadrupole QCS and without BELLE II; Phase 2 has the IR quadrupoles QCS and the BELLE II solenoid (but still without the VXD vertex detector); and finally Phase 3 has the full BELLE II detector. Phase 1 is for the initial beam commissioning, low emittance tuning, and vacuum scrubbing, and has un-squeezed IR optics. The damping ring is not needed in this phase. During Phase 1 the two rings can be operated with a beam current up to half the design value. For example, the bunch population could be the nominal value but with half the number of bunches. Phase 2 will be used to commission the low beta optics, as well as for correcting coupling, bringing beams into collision, background studies, and DR commissioning. The target luminosity for this phase is $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. Phase 3 will start true physics running.

Concerning the magnet and vacuum status, the arc sections will be almost complete by the end of March 2014. The main remaining magnets in the arcs are the 24 sextupoles with tilting tables, which will be installed next fiscal year. In the Oho and Nikko straight sections the wigglers and beam pipes are already installed.

So far around 930 beam pipes are baked and coated, and about 830 beam pipes installed. The production rate of new beam pipes is 10-15 per week. The remaining 300 beam pipes will be completed during the next fiscal year. The LER arc chamber is made from Al; the LER wiggler requires a copper chamber with an antechamber.

The on-going alignment work of the components in the tunnel is complicated by tunnel movements over the year from both natural ground movements and from tunnel level changes due to other on-site construction activities. In particular the effect of the construction of the new injection tunnel for the AR is clearly seen in the survey results: the SuperKEKB tunnel level changed by 1.5 mm in 1 month underneath the new tunnel. Other relevant ongoing construction is related to the new utility building. Final alignment is planned for later in FY2014 prior to the start of beam commissioning.

Most of the remaining work is concentrated in Tsukuba straight section. The design of the near-IR beam pipe has been completed, and its fabrication is scheduled for next fiscal year. The IR magnets are now in fabrication, and will also be installed next fiscal year. The mini-shield around the IR will be installed for Phase 1.

The IR SC magnets will be completed by December 2014 (the original target date had been December 2013). The cryostat for the right side SC IR magnets will be completed only in July 2015, which means that there would be no time in the original schedule for cold testing these magnets before installation in the beam line.

The SuperKEKB RF must handle three times the beam power of KEKB. To this end, the power couplers of the ARES cavities will be replaced by ones with stronger coupling (half of these will be ready for the Phase-1 commissioning). Two RF cavities for the damping ring are under production, based on the ARES design but without a storage cavity. The first production cavity exceeded specification. The second cavity is in production and should be completed in this fiscal year.

Production of the BPM system and other beam diagnostics is well advanced.

The general water-cooling system capacity was reinforced using pipes of a larger diameter to increase the cooling capacity around the ring by a factor 3.

The damping ring tunnel was completed in March 2013. The associated machine building and power supply building will be finalized this month (March 2014).

Finally, the budget, schedule and human resources remain a concern. On the positive side, the full 314 oku-yen construction budget could be secured, and the planned KEK part of the construction budget will be fully supplied. On the other hand, there has been a deep cut in the FY 2014 operations budget. Namely only 25 oku-yen were appropriated for fiscal year 2014 instead of the requested 36.9 oku-yen. Under these conditions it will not be possible to start beam operation in fiscal year 2014. However, with the available budget the construction can be finalized and the commissioning of machine components can be started in March 2015. Efforts are underway to recover the original budget, but not much time is left, given the need to place contracts ahead of time.

An alternative commissioning schedule has been worked out for the reduced operations budget. The impact of the budget cuts is to delay the start of Phase 1 by 4 months, and delay

Phases 2 and 3 by 7 months each. Phases 1 and 3 will be interrupted by summer shutdowns, which causes the additional delays.

The number of staff members supporting work on the upgrade of SuperKEKB is growing very slowly and has increased by only 5 FTEs over the past two years.

A response to a recommendation from the last MAC meeting, a single person has been assigned to serve as the “impedance police”: Demin Zhou was appointed for this role.

Overall, an impressive amount of work has been accomplished and the construction is on schedule to start Phase 1 commissioning in 2015. The most critical remaining activities are cabling and piping.

Recommendations

The critical path for the completion of SuperKEKB construction is in completing the work on cable and piping installation. Care is needed to make sure these activities stay on schedule.

Alignment must be watched carefully to see if previously aligned hardware needs to be realigned after subsequent ground motion.

The beam in the Damping Ring (DR) needs to be aborted when the SuperKEKB rings abort their beams. The location and design of this DR abort system needs to be finalized and constructed to be ready for high current operation of SuperKEKB.

The schedule to complete SuperKEKB construction and the start of beam commissioning is complicated by potential changes in the expected funding of beam operation. The schedule can be firmed up a lot after the new JFY2014 budget is finalized in April-May 2014. In case the FY2014 budget cut remains unchanged, a modified schedule should aim at profiting as much as possible from the additional 4 or 7 months, e.g. so as to include the cold testing of right-side IR magnets prior to installation and to complete the vacuum-system set up.

Now that the construction effort is starting to ramp down, the needed additional number of staff members going forward should be reviewed to reflect the new work load.

3) Belle II Physics, Schedule, and Construction Status

Belle II will be the upgraded particle physics detector at SuperKEKB. Belle II has about 600 collaborators in 23 countries at 95 institutions. The physics case for Belle II is very strong. One physics motivation of Belle II and SuperKEKB is to look for new CP violating phases and new quark-flavor changing reactions, as predicted by most standard-model extensions, and thereby to search for new physics beyond the standard model.

The expected higher background (the event rate is ~10-20 times higher than KEKB) requires improved detector performance. In addition, the new beam energies at SuperKEKB to reduce the beam emittances imply a lower boost factor than for Belle, which is addressed through new technologies for PXD and PID. A high-speed readout will mitigate the increased background level.

Overall the technical upgrades to Belle II are going well. The critical path items are the VXD chamber and the TOP counters.

For the PXD ladder, a first sensor will be available in October 2014 and the full production will be finished in June 2015. The forward sliding mechanics of the SVD is under test. An integration test of the VXD (PXD+SVD+DAQ) was done with a 6-GeV electron beam in January 2014, which enabled alignment and fine parameter tuning. A small cell chamber of the central drift chamber was recently tested with cosmic rays. Particle ID detection (barrel

and endcap PID) is based on the timing difference of Pi and K due to different emission angles of the Cerenkov radiation.

The time-of-propagation (TOP) counter will undergo a US DOE CD-2/3 enabling review in March 2014, which will be an important milestone. In a beam test, a timing resolution of 60 ps was demonstrated, while the target value is 35 ps; further improvement toward the target is ongoing. A cosmic ray TOP test bench is being prepared in the Fuji hall. The partial TOP installation is scheduled for February to March 2015, which is a very tight schedule.

An ARICH beam test has been performed at DESY in May 2013. Mass production of HAPDs is going well, although slightly behind the target rate. The ARICH should be ready in December 2014 and a full system test is planned for January 2015. Other sub-detectors in progress are the Electromagnetic Calorimeter ECL (all functions of collector board tested last year) and the endcap and barrel K_L and muon systems (RPCs replaced by plastic scintillator structure).

Sub-detectors will be installed by June 2015; the roll-in of the detector will start in July 2015 (except for VXD system, part of TOP). The schedule is tight for the VXD (SVD ladder, PXD sensor) and for TOP (quartz production) to be installed after commissioning Phase-II.

The initial physics running (i.e. SuperKEKB Phase II) will operate with a partial particle ID counter and without a Vertex Chamber (VXD). The question is at which beam energies to operate in Phase II so that the data is useful for physics. One possibility is to operate at the standard Upsilon (4S) resonance during this period. An alternative would be to operate at other resonances, like 2S, 3S ... where the pi/K separation is less critical, and where small data samples were accumulated by previous experiments (Babar, KEKB and CLEO). This energy choice should be made around the fall of 2015, so that advanced preparations can be made.

There are many examples of accelerator and detector data that need to be shared between Belle II and SuperKEKB, such as hardware status, beam abort triggers, pre-abort data, luminosity signals, hardware interlocks, collimator settings, and background signals. Included here is the ongoing new controls activity linking the DAQ interfaces of detector and accelerator for beam abort and collimator control. The full list of signals should be agreed on and formalized soon so that both sides can complete the needed electronic controls by Phase II beam running.

Recommendations

Belle II and SuperKEKB management teams should decide the run objectives and parameters for the early physics running in SuperKEKB Phase-II commissioning by fall JFY2015.

Belle II management should monitor the status of essential Belle II contributions from international and national partners.

Belle II and SuperKEKB control teams should determine soon the full list of control data that need to be shared between the two machines and the electronic exchange mechanisms.

4) Beam Dynamics Issues

Results of weak-strong simulations of the beam-beam effects in the nano-beam collision using a linearized arc were presented, as well as error tolerances for IR optics, beam-beam simulation results for a realistic arc containing lattice nonlinearity, and the simulated impact of space charge.

A tune-scan of beam sizes and luminosity, with the HER beam fixed, reveals strong synchro-betatron resonances for the LER. The design luminosity of $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ can be achieved with a linear arc by choosing the working point between resonance lines. Repeating the same exercise for the HER with the LER beam fixed, shows a similar luminosity performance, but with less pronounced synchro-betatron resonances.

The crab waist would be a very powerful means to suppress the resonances of the LER. Unfortunately in practice the crab waist degrades the dynamic aperture due to the nonlinear optics between IP and the crab waist sextupole.

IR error tolerances were determined through beam-beam simulations, and an error table was produced for the weak beam. The tolerances are similar to those for KEKB since the beam-beam tune shift is similar. Apparent differences in the coupling parameters are related to the different beta values, and should largely disappear when converting to normalized coupling parameters.

Beam-beam simulations were performed with a realistic lattice using the code BBWS. Crosschecks are planned with ACCELERATICUM (BINP), BMAD (Cornell), SCTR (a new code by K. Ohmi), but have not yet been done.

Plotting the simulated specific luminosity versus the product of the bunch currents for the LER simulation shows that including the lattice nonlinearity reduces the luminosity by 20-30%, and this loss starts to occur at very low current. Chromatic terms up to 3rd order in δ , including chromatic coupling, do not explain this degradation seen in the SAD simulation and weak-strong beam-beam interaction. The beam distributions from the nonlinear SAD simulation also show much larger beam tails than the BBWS simulation with linear arcs.

No such degradation at low current is seen in the HER, and the observed degradation at high current can be fully explained by the chromatic effect.

Adding space charge to the beam-beam simulation results in an even larger luminosity loss of 65%.

The electron cloud instability was analyzed with a simple model, as well as by considering a realistic lattice and a realistic s -dependent electron-cloud density distribution. The incoherent effect of electron cloud in the high beta region was also explored in simulations.

The simple model estimates the instability threshold for an electron density of around $2 \times 10^{11} \text{ m}^{-3}$, which is roughly consistent with direct simulations.

The beta functions near the IR are high, up to 3000 m. Two scenarios for the electron distribution near the IR were considered, with either high or low density of electrons in the high-beta quadrupoles. The corresponding simulated instability threshold is either 4 or 6 times the design value, respectively.

Simulations below threshold were performed including radiation excitation and damping. Some emittance growth is observed if the electron density is larger than the design, e.g. a 20% increase for twice the design electron density.

The electron cloud density near the IR is dominant for both the instability and the emittance growth.

Since the beam pipes are equipped with antechambers that remove many of the photoelectrons, secondary electron emission is an important process for the creation of the electron cloud, even with TiN coating.

Recommendations

Try to determine, and then correct, the nonlinear terms that lead to the luminosity degradation when LER lattice errors are included.

Pursue benchmarking simulations with other codes to confirm the SAD results.

Repeat beam-beam simulations with space charge for other working points.

Perform strong-strong simulations including LER space charge.

Study the effect of RF phase modulation due to the abort gap in beam-beam simulations.

Provide a set of beam-beam simulations supporting the knobs normally used in experimental luminosity tuning (x-y collision offset, x-y coupling, waist position scan, etc.)

5) Impedance Issues

Impedance calculations have been performed for most beam-pipe elements using a variety of calculation approaches and simulation tools. Longitudinal pseudo-Green wake functions have been computed for the combination of most elements, except for a couple of items (the LER clearing electrodes might be among the more important missing ingredients). CSR and Coherent Wiggler Radiation (CWR) impedances are significant for the pseudo Green function wake, but appear negligible for the long bunch wake. A tentative conclusion is that, for either ring, CSR and CWR are not strong in the absence of microbunching.

With the expected rms bunch length around 6 mm, the total HOM power at full current is about 1 MW for both HER and LER. 100 kW are dissipated at the HER collimators. Absorbers are installed on either side of these collimators.

Simulations with the pseudo Green function wake fields indicate about 20% bunch lengthening and a simulated rms bunch length around 5.8 mm at the design beam current for either ring. The simulated microwave instability threshold is 17×10^{10} particles per bunch, two or three times higher than the design currents for the LER and HER respectively. A noticeable potential-well distortion is predicted in addition to the bunch lengthening, which could have an impact on the luminosity performance.

A recent theory by Y. Cai on CSR in a rectangular chamber predicts a much lower CSR-instability threshold for a square chamber than for two parallel plates. The threshold given by Cai's formula is below the design current for all three rings (HER, LER and DR), and in the case of LER and DR by a significant factor of 3-5 below the design. This estimate is in contradiction to previous simulations performed at KEK.

Longitudinal CSR has also been examined for the J-ARC, evidencing a multi-bend interference.

Asymmetric beam pipe geometries can lead to a transverse tilt. Relevant formulae were derived by Stupakov and indicate that this could be a relevant effect.

The vertical TMCI threshold, dominated by the collimator wake fields, is 15-20% below the design current, assuming nominal collimator positions.

Beam measurements of the impedance are planned for 2015.

Recommendations

Include potential-well deformation and longitudinal wake field in the beam-beam simulations and check the effect on the luminosity.

Consider lab bench measurements of some potentially critical impedances, e.g. for collimators and clearing electrodes.

Continue the KEKB-SLAC collaboration on CSR-CWR effects on the bunch stability with the aim to settle up discrepancies in the threshold estimations. Pursue beam-based benchmarking measurement of Y. Cai's theory at a suitable accelerator.

Complete compiling a comprehensive impedance budget for the Main Rings and Damping Ring.

6) Optics Issues

Simulations of the magnetic optics lattice with all the expected random errors lead to larger vertical beam emittances than required. These increases can be corrected though a long series of correction steps. To achieve consistent vertical emittances at the picometer level, the usual techniques (such as orbit, dispersion, coupling, and beta function corrections) are used, followed by sextupole, skew sextupole, octupole, chromatic phase advance, and chromatic x-y coupling corrections. 100 sets of errors were tried with these correction schemes and all lattices were acceptable after corrections. The resulting estimated Touschek lifetime of the beams is about 600 seconds.

The design studies of LER and HER lattices are progressing aggressively. The preparation for Phase 1 and Phase 2 commissioning seems to have identified enough tools to deal with known errors. However, the working lattice with the IR section in Phase 3 for both commissioning and operation is still a concern. The lattice preparation for optics corrections for the various commissioning periods looks reasonably well developed.

A new issue in optics presented this year is the impact of the beam-beam effect on the Dynamic Aperture (DA). A specific feature of the nano-beam configuration, which has a large crossing angle, is that large horizontal displacements of a particle (tracked in DA simulations) translate to appreciable longitudinal offsets of the collision point. The residual x-y coupling leads to a vertical displacement, and the collision results in a large vertical beam-beam kick producing an actual beta-y many times larger than the nominal beta-y*. The nonlinearity of the beam-beam kick results in dynamic instability of the vertical motion and thus reduces the dynamic aperture. The horizontal betatron and synchrotron tunes modulate the beam-beam kick, thus the effect of DA reduction should be strongly tune-dependent. Nonlinear optics corrections may be helpful if the nearby resonances can be cancelled or weakened.

This beam-beam dynamic aperture effect reduces the beam lifetime to about 200 seconds, which is quite short for a collider. The Committee recommends that an acceptable solution to the beam-beam dynamics aperture effect be found with the aim of increasing the lifetime to about 600 seconds where the luminosity lifetime dominates the overall lifetime.

Ideally, the crab waist correction scheme can be a strong cure for the beam-beam dynamic aperture issue. However, when the crab waist sextupoles (which are required to produce the crab waist) are included in the simulation, the dynamic aperture is again strongly reduced. An acceptable combination of crab waist and beam-beam dynamic aperture effects must be found, which may take considerable design work to be successful.

Recommendations

The Committee suggests that the optics group look into the harmonic statistics information from the magnet measurement group to update the field error simulations, to evaluate the

results of the cryogenic measurement information of the SCQP, and to check the performance of the field leakage correction coils.

For Phase 3 commissioning, more effort to clarify the beam-beam effect, crab-waist, and improvements to the overall lifetime towards the design value should be applied to make the Phase 3 luminosity target more credible.

The tune dependence of the reduced dynamic aperture due to the beam-beam effect should be further simulated.

7) IR Overview

The design of the accelerator interaction region is a remarkable combination of sophisticated technologies: mechanical design (extended apparatus, torques and forces, tight tolerances, insertion and extraction), vacuum system (pumping, surface coatings, electron stimulated desorption, flanges at inaccessible locations, and reduced backgrounds), thermal (beam-induced heat load from radiation and wakefields with nearby superconducting magnet cryostats), electrostatic and electrodynamic (gold coating, beam instrumentation, and beam wakefields), and finally metallurgical (joining dissimilar metals, welding, and forces from differential heating). There are concerns about the air leak found in the central pipe.

For Phase I commissioning the superconducting quadrupoles and associated vacuum chambers will not be installed. The concrete shielding, vacuum chambers, and beam diagnostic for commissioning Phase I are completed or on order. The upstream and downstream vacuum chambers and magnets outside of +/- 4 m will soon be ready for installation. In Phase I there will be a concrete shield surrounded the IR so that beam can be commissioned while the workers for Belle II can be in the adjacent hall to work on the detector while in a "Warning Access Level" (meaning less than 0.2 microSv/hour).

A series of concrete modifications to the support piers are done or will be started soon.

The upstream and downstream vacuum pipes are very long (~4 m) having a common left-right mechanical connection near the Beryllium chamber. There is no vacuum pumping over +/-4 m as agreed to by the Belle II detector as there is no space for internal or external pumps. The potential use of a vacuum simulation code is recommended to predict the vacuum profile in the IR region. This would be a good task for a young vacuum person leading to an optimized choice of vacuum pumping outside the IR beyond 4 m. The calculation of the pressure profile during the scrubbing phase profile is also very important to predict the validity of the concrete shielding. The simulation should take into account also methane degassing: the nearest pump to the interaction point has a very low pumping speed for CH₄. The indication that 'the average pressure in the IR region will be 10⁻⁶ Pa or higher' should be further investigated in detail with the hope of understanding the maximum pressure and making it as low as possible and consistent with Belle II operation.

In the present design, there is no TiN coating in the IR region. It is not clear if scrubbing would be as efficient as in the rest of the accelerator. It is also not clear where solenoids could be installed in case electron cloud appeared in the IR chambers.

There have been thoughtful considerations given to making the longitudinal beam line vacuum connections at the IR region near the Beryllium chamber with two plans investigated. A productive collaboration has been made with a group at DESY to explore the "remote vacuum connection". A good solution is not yet defined. It is not clear when a decision will be taken and on which criteria.

A mirror for a Large-Angle Beamstrahlung Monitor (LABM) has been added in the IR vacuum design to allow a new kind of monitor to be used at SuperKEKB to measure directly the IR beam luminous size. This monitor will be built as part of the US-Japan program.

A temporary background measuring apparatus (BEAST-II) will be installed in the IR for commissioning Phase I. BEAST-II will measure and verify the beam background simulations used to make predictions for Belle II.

The Radiation Control Group should evaluate whether the larger backgrounds in the IR with SuperKEKB will lead to significant residual activation of the IR vacuum chambers. A possible consequence could be that if the IR region vacuum chambers need to be worked on, they may be too activated to quickly initiate a repair.

Recommendations

Finalize the vacuum chamber designs for Phase II within 4 m of the IP and proceed with engineering.

Perform laboratory tests on the reliability of the “remote vacuum chamber connection” under vacuum conditions.

New calculations of the expected vacuum pressures in the IR should be completed including the new chamber geometry, surfaces, and beam conditions.

8) Final Focus Magnets

All superconducting quadrupole coils are completed for the final focusing system. Follow-up procedures are progressed in collaring, end plates with v-groove keys, field measurements, assembling with correctors and field canceling coils, and then cryostats. After accumulating manufacturing and assembly experiences at Mitsubishi, the final focusing magnet team obtained very good results in field measurements within the sextupole error of 10^{-3} with respect to quadrupole fields. The field of quadrupole magnet was excited at room temperature with 1 Amp current and the signal was amplified to simulate the field at the designed current of 1,625 Amps.

The collaboration with BNL on SC correctors is also progressing smoothly, and it will be completed by September 2014. The shipped SC correctors were tested in a vertical cryostat with excitation up to 70 A without quench. The field strength of these correctors can provide adequate correction. The leakage field of the quadrupole was analyzed with Opera3D and excitation of cancel coil has the strength to cancel the leakage field.

The left side cryostat is scheduled to be installed by the end of 2014 for the Phase I commissioning. The right side system will be completed by July 2015 for testing in the third quarter of 2015.

It is urgent to have these SCQP magnets tested in low temperature. The magnet contraction might affect the structure and multipole components ratio of the superconducting quadrupoles at cryogenic temperature. The Committee would like to know the measurement results once the superconducting quadrupoles are shipped to the site. The field mapping results should be provided to the Optics group to analyze the effects on lattice. The Committee expects that the rest of the work would progress smoothly as planned.

9) Beam Background

Belle II will operate in a difficult accelerator environment with potentially troublesome backgrounds. Belle II must be able to take good, clean data in a situation that has increased backgrounds compared with Belle. Extensive simulations have been carried out to predict

sub-detector occupancies and plan mitigation strategies for the various background sources. The simulation studies will continue.

As previously identified, the background-generating processes considered are Touschek scattering, beam-gas scattering, radiative Bhabha scattering, 2-photon events, and synchrotron radiation. The computer simulation tools used to model these processes include SAD, BBBREM, BDK, and Geant4 (for SR). The simulations include all the vacuum chamber physical apertures, magnetic fields, collimator settings, tungsten IR shielding, and the 10 micron Au coating of the vertex chamber.

In recent studies, the PXD occupancy was predicted to be 2-3%, close to the acceptable limit. Also, there is a reduced lifetime from radiation of the old TOP PMTs that is a concern. New at this review were: an update on the radiative Bhabha cross section (reduced due to the “beam-size effect”), a full detector simulation (8th campaign), and work on joining the DAQ from detector and accelerator for beam aborts and collimator control.

The background from Touschek and Coulomb scattering is mitigated by careful placement of collimators. The IR background is dominated by radiative Bhabha scattering, the cross section of which has been modified. Introducing a cut from the beam-size effect decreased the loss by ~20%.

Various new shielding ideas for neutrons and against electromagnetic showers were explored in the 3D Geant4 simulations.

The full detector simulation yielded the following recent results. The PXD occupancy due to 2-photon scattering is about 0.8%. The additional contribution from synchrotron radiation SR is less than 0.1%. The total value of the drift chamber occupancy decreased by a factor 2-3 from last year’s value. In 2013 the SR contribution to the PXD occupancy had been estimated as $1.1\% \pm 0.3\%$ (increases to $1.6\% \pm 0.3\%$ if misalignments of the vacuum chambers are included). Other changes since 2013 include an optics update optics, a more realistic Be-Ti junction shape in the simulation (where the Be component has gotten shorter), including a 10-micron Au plating layer not only on the Be chamber but also on Ti components. Finally, a modified beam-pipe shape was added, which reduces the possibility of single-bounce synchrotron radiation hitting the Beryllium part.

However, for the TOP chambers, the old design PMTs will still be strongly damaged in a few years at full luminosity. The old PMTs have a lifetime of 1 C/m^2 , whereas the new design PMTs are 7 times better. Unfortunately, 60% of the old-type PMTs will need to be used as the budget does not cover the cost of replacing them all.

The CDC/ARICH neutron rates are suppressed by the new shielding; shielding “type 2” with more tungsten is preferred.

It was discovered that a wrong lattice file had been used for the LER simulation previously. As a result the radiative Bhabha background may increase and become as large as for the HER. The effect on the TOP PMT background is now under detailed investigation with an expected increase by a factor of two.

The latest simulations indicate that a PXD occupancy of 0.003% is to be expected due to synchrotron radiation. The effects of halo effect and misalignments are still missing and should be added.

Work is ongoing on the joint Belle II and SuperKEKB DAQ interface, which includes an interlock triggering the beam abort, abort loggers for analysis, and collimator control (about 50 parameters) with a semi-automated control algorithm for optimized background. It is

planned to use information from the IR loss monitors mounted around cryostat at sensitive locations to disentangle background sources and to aid with the collimator control.

Recommendations

The lost particle cutoff introduced due to the “beam size effect” should be rechecked. It may be that the condition for the cutoff is not “an impact parameter less than the beam size” but “an impact parameter less than half the mean distance between two adjacent particles in the rest frame” (For example, see that “density effect” from H. Burkhardt, R. Kleiss, “Beam Lifetimes in LEP”, EPAC94).

The synchrotron radiation background should be simulated with realistic beam tails as predicted by beam-beam simulations.

The effect of closed orbit errors in the IR region on the background should be investigated to determine the associated tolerances on the absolute orbit and on short-term orbit changes.

The backgrounds should be recalculated with the latest optical lattices for LER and HER.

10) Collision Feedback

The nanobeam scheme and IP/final focus design will require a closed loop feedback system to keep the beams in collision and achieve the desired luminosity. The SuperKEKB team has approached this challenge with dedication and we respect the care that has gone into the estimation of the vibration of the final focus magnets, as well as the design and estimation of the necessary performance of the vertical and horizontal collision feedback.

The mechanical supports and structure of the final focus magnets have been studied, and significant engineering has gone into stiffening the concrete and structural elements. Finite-element codes have been used to estimate the resonance frequencies and expected amplitudes of the structural motion in response to expected noise excitation. We acknowledge the care and completeness in these studies. We also thank our hosts for the tour of the mock-up of the IP region.

The proposed vertical and horizontal feedback systems use beam-beam deflection, sensed in a BPM system for the vertical plane motion, while the horizontal position error is sensed and corrected through a luminosity measurement in conjunction with dithering of the horizontal beam position. Air-core correction magnets are used to apply steering signals to the beams to maintain collisions. There has been excellent progress in fabrication of the correction coils and horizontal and vertical correction magnets.

One observation for the modal motion plots is that the final focus magnets will not be moving in orthogonal vertical and horizontal directions, but in some superposition of motion. We think this coupled motion is likely to be seen in the signals in the horizontal and vertical error signals, and we suggest some effort be made to estimate the impact of this sort of crosstalk in the error signals and possibly in the actuators. The closed-loop bandwidths for the two loops are very different, and continued studies are needed to understand what sorts of performance might be achieved during the commissioning phases and then at the final operating configuration.

There has been significant effort to model the dynamic response in the vertical plane, with simulation of the closed loop dynamics, including frequency-domain models of the BPM processing, the air-core magnet and eddy effects in the vacuum chamber, the frequency response of the power supply driving the magnet, and a PID control loop. We respect the effort and especially thank Dr. Fukuma for both his presentation and informal discussions

with the committee about the structure of the models used in the closed loop studies, and the quick estimation of the gain and phase margins in the PID control loop.

We agree with the overall model approach, and think that the soon-to-be improved models for the power supply will help estimate the loop dynamics. We look forward to continued studies, and think attention to the closed loop responses with more sophisticated models of system elements will help develop methods to optimize the dynamics of the actual system. It may be helpful to drive the simulation with a test vibration excitation, and use the responses to optimize the PID loop parameters of step response, damping, settling time, etc., just as will eventually have to be done in the final system.

The horizontal system will require the use of the luminosity measurement to generate an error signal. It is proposed to use a lock-in technique to generate a correction signal from the luminosity signal in response to a modulation of the beam overlap. We have not had much quantification on this luminosity signal, what sort of S/N and bandwidth it will have as a function of luminosity. We think it will be helpful to get some estimates of the noise in this signal, as at low currents, large beam cross-sections, the luminosity will be lower. We think some estimations of the dynamics of the horizontal dither, the error signal, the S/N, will help the design team understand the tradeoffs in the selection of the depth of the dither signal, the modulation frequency, the choice of loop bandwidths, etc.

We also are not clear if the luminosity signal is a digital number, computed from counts in various detectors – if so we mention that there really isn't a need for the analog lock-in hardware, as the synchronous demodulation can be done as a software process on the digital luminosity signal.

We look forward to seeing the continual progress and development of these systems.

11) Magnets and Power Supplies

There are only 11 members in the main-ring magnet system group. Their tasks include magnet design and installation, field measurements, survey and alignments, power supply design, testing and cabling, connecting cooling pipes. An enormous amount of work has already been accomplished on schedule. The Committee appreciates this very professional accomplishment.

Most of the dipole and quadrupole magnets are installed. The sextupole and steering magnets will be installed this year. The total number of magnets is about 2,500. Field mapping of more than 500 new magnets were conducted. Field mapping results indicated good manufacturing and quality control for the new magnets. The standard deviations of dipoles of the field center and integral field are $1.9 \cdot 10^{-4}$ and $3.3 \cdot 10^{-4}$ respectively.

Precise alignments were conducted taking into consideration the expected variation of the tunnel temperature of 10°C. There is heavy civil construction work for the utility building and AR tunnel, and the ground level has been changing rapidly in time. They observed 2.7 mm changes over a three-month period. It is expected that these constructions will be completed by the summer, after which the ground level should become more stable.

Tilting tables were produced for 24 skew sextupole magnets allowing a rotation of $\pm 30^\circ$ with the axis accuracy of less than 0.1 mm

There were more than 2,300 power supplies in KEKB. Most of them were reused and 620 of them were overhauled. 390 new units are manufactured including MW-class power supplies. About 280 circuit breakers were replaced in 8 power supply buildings. Cooling pipe connection and power supply cabling jobs are also carried out in parallel

The Committee congratulates the team an excellent job in keeping the installation going smoothly towards Phase I commissioning in January 2015.

Recommendations

The field mapping information should be provided to the Optics group as soon as the data is confirmed.

The Committee would be interested to have the histogram of jitter and drift of these power supplies. This information should be compared with the specification from the Optics group.

12) Magnet Supports

The QCS supporting system was redesigned and manufactured including a moving stage and a high precision surface floor. A 3-D model was set up to simulate the deformation of the support structure in both the vertical and axial directions due to the self-weight and magnetic forces. The metal support and movable frame is under production in a factory. Assembly at KEK is scheduled for the middle of March.

The concrete floor for the QCS supporting area was modified to have precision flatness to mount the movable supporting frame. The resonance frequencies of the concrete structure were analyzed by the Finite Element Method (FEM) and compared with measurements. They are in good agreement each other. The surface of high precision floor was formed by self-leveling of an epoxy resin on top of the reinforced concrete structure. The flatness of the floor was measured by a laser tracker to be within 0.1 mm over the area of 1.8 x 8.0 m.

13) BPM and Bunch Feedback System

There has been continued progress since the last review. The team developing the diagnostics and feedback systems is building on the experience and technology successes from KEKB, and there is depth and sophistication in the system in development and production for SuperKEKB. Many of the system features and designs have been reviewed in past MAC reports. This year there is news on production of hundreds of modules, pickups, and plans for commissioning these vital beam diagnostics.

The BPM systems are based on narrowband detection. A 1 GHz detection scheme is used in the HER while a 509 MHz system is used in the LER because of the vacuum chamber dimensions. The HER systems are refreshed KEKB modules, while the production is well underway for the new 509 MHz systems. Testing of the initial production shows the S/N of the production receivers is better than specification, and the design team should be proud. The wideband gating functions, used to select a single bunch signal from the BPM signal path, are in production. The measured data shows excellent isolation of the selected bunch, and minimal gating transients.

The presentation did show examples of fabrication difficulties and damage to some number of the coax pigtailed used to connect the BPM buttons to the processing systems. This is a concern, and it is impressive that the team discovered this because of their own careful testing and quality checks. We think it important to understand if these issues were the result of incomplete testing by the cable manufacturer, or some mechanical damage that occurred during installation. We think learning from this experience is valuable not only for KEK but for other labs who use these types of heliax cable assemblies.

The system design includes displacement sensors on the BPM assemblies, and the presentation has no specifics on these, how they are read-out, etc. We are curious and hope to hear about them and their value in the BPM systems and commissioning at a future review.

The diagnostics group has also prepared the detailed designs of the pickups and feedthroughs for the damping ring BPM systems; the work seems on track to a successful conclusion in the next year. The DCCT and other diagnostics are ready for commissioning, while orbit interlock/abort systems are in the final stages of development. We do not see any concerns for their readiness.

The bunch-by-bunch feedback systems are a particular strength of the KEK team and all should be proud of the history of successful development of these systems. Transverse systems and diagnostics are in place for both rings, and a longitudinal system will be implemented in the LER. We repeat our comments from last year that the high-current operation of the systems will require vigilance in monitoring the beam induced power in the kickers and amplifiers.

We are confident in the plans going forward to commission these systems and compliment the team on their readiness for the upcoming commissioning phase.

14) Photon Monitor and Loss Monitor

Development of three type photon monitors for beam diagnostics at Main Rings and Damping Ring has achieved impressive progress since the last Review.

Synchrotron radiation monitors SRM (interferometer, gated camera, streak camera) are envisaged to measure the beam sizes in three dimensions at the DR. In the MR, the horizontal beam size measurement is the main purpose, while the vertical beam size measurement will be at the limits of the resolution, although it will be useful for cross-calibration at larger beam sizes. The interferometer is well advanced, with the diamond mirror, mirror holders and extraction window and chamber in fabrication and integration. For thermal stability, the extraction mirrors are made of (nearly) monocrystalline diamond, gold-coated, to withstand the heat load from a 400W SR beam. The mirror is mounted in a 24 mm high antechamber. The floor of the hut has been strengthened to reduce the vibration effects on the interferometer. Together with vacuum components and optical transfer lines, the whole SRM schedule is well matched to the requirements of the Phase I MR commissioning. Meanwhile the SRM components for DR, including extraction mirror, transport line, streak camera, gated camera and optical elements, are ready to be installed and integrated.

X-ray monitors (XRM) in the MR that provide the necessary resolution for the vertical beam size measurement have been being developed for shot-by-shot measurement using the coded aperture imaging technique. Based on the coded aperture tests at CESR TA, ATF2 and DIAMOND LS, (where a high-efficiency pixel detector equipped with a 64-channel readout/digitizer system is linked with EPICS), the XRM for the SuperKEKB HER and LER have been well designed and developed, including XRM beamline, detector, spectrometer, readout system. Remarkably, in addition to the bunch-by-bunch measurements, the sharp rise time of this device gives hope for a head-tail separation in a 5 mm long bunch, with appropriate signal analysis. The component fabrication and integration are under way, and the construction schedule is well matched with the phase I commissioning.

The Large Angle Beamstrahlung Monitor (LABM) for collision offset and size mismatch measurements is a necessary part of SuperKEKB for achieving high luminosity and low background operation, it has being developed in collaboration with Wayne State University and is in excellent shape; most of the LABM components, including optical boxes, optical transfer beamline, components, readout electronics, are either fabricated or in fabrication. The schedule is well matched to the requirements of SuperKEKB commissioning. It may be ready for first tests already at Phase I, to be fully commissioned at Phase II.

With almost all components on hand, the beam loss monitors are ready to install. Beam loss monitors are upgraded, widely re-using components from KEKB, while new ones are being prepared for the DR, to be ready this year.

The Committee is satisfied that the Photon Monitors and Beam Loss Monitors are on a fast track, so that these essential diagnostics will be ready by the time for MR and DR commissioning.

15) Vacuum Construction Status

The installation of the vacuum chambers is progressing very well. All components have been ordered. For the LER, 87% are already delivered, 30% for the HER. Despite the very tight schedule, there is no doubt that the vacuum system will be closed in due time. Most of the special chambers are already in the production phase, in particular those for the beam abort and for the bifurcation of the X-ray line.

The TiN coating of the positron ring is completed for the delivered beam pipes. The vacuum chambers are almost all installed. A minor issue of interference with the magnet coils were identified and solved. The evacuation is started in both rings.

An unexpected number of air leaks (10%) has been found in the connection between bellows and main chambers. The reason for this problem seems to be a deformation of the flanges or a defective machining of the aluminum gaskets. Investigations are ongoing. The procedures for installation and leak testing should be prepared. Of particular concern is the exposure time of the TiN coated vacuum chambers to the air of the tunnel. A long stay could change the secondary electron yield of the coating and so a longer scrubbing time could be needed.

The change of the control of the vacuum system is progressing. Finally, it will have the same standard of the rest of the machine. The control will be based on EPICS, the database on Ethernet protocol. Several vacuum elements, i.e. gauges, ion and NEG pumps, are already integrated in the new control system.

Indications about the pressure interlocks and their logic was not presented. It is not clear which threshold will be used for the closure of the gate valves or for the protection of delicate components.

16) TiN Coating and Baking

The bakeout and TiN coating is progressing at the right pace: 925 beam pipes have been baked and, among them, 805 have been also coated. This is an impressive achievement.

By the end of the year, 450 beam pipes are to be coated, including the 100 chambers for the DR. The baking and coating activities are going to restart in April after 5 months of planned interruption. While waiting for the delivery of new chambers, the team has been modifying two of the horizontal systems for the coating of the bent DR chambers. For this purpose, the shape of the cathode has been changed to be adapted to the large aspect ratio of the beam pipe cross-section. The cathode has the same bending radius as the DR chambers. Ceramic-isolated holders ensure the positioning of the cathode in the horizontal position. The team of 10 people who carry out this activity have become very skilled at performing these procedures, now considered routine. There is no showstopper for future production: the chambers should be available for installation as planned.

Quality control relies on visual inspection, monitoring of the coating parameters, and the ultimate pressure after bakeout. The latter measurement shows a peak in the statistical distribution of the ultimate pressures between 1 and 2×10^{-8} Pa. However, ultimate pressures

higher than 5×10^{-8} Pa have been measured for more than 100 vacuum chambers. Unfortunately the reason for this long statistical tail can no longer be identified because the residual gas was not analysed systematically, and there was no systematic measurement of the secondary emission yield (SEY) during the production. This means that unexpected events in the production chain could increase the secondary emission without being tracked (for instance, air leaks during the coating process).

SEY measurements performed before the beginning of the production run have shown the exceptional behaviour of the TiN coating (SEY peak lower than 0.8 after an electron dose of 10^{-2} C mm⁻²). However it is not clear if the low SEY is conserved after air venting and, if not, what is the scrubbing time needed to re-eradicate the electron cloud effects in the chambers without grooves.

17) Collimators

Collimators are indispensable parts of SuperKEKB, required to overcome background issues in the detector. The HER will reuse the existing KEKB collimators, while the LER will employ 10 new horizontal and 3 new vertical collimators, which have movable tungsten heads (tip) in the vacuum chamber with efficient cooling. A prototype has been developed and long duration tests of RF finger moving have been performed, which shows the finger structure and contact surface need to be improved for the long duration movement without dust-generation and finger-breakage.

The development of the prototype and the mock up shows good progress, but the high impedance of the structure is still a major concern for the new collimator; it needs a comprehensive and coordinated study to confirm the TMCI control requirement. This may lead to a program to optimize the collimator geometry or to find a new collimator scheme or structure. Some detailed considerations are:

Impedance calculations do not take into account where the impedance losses are adsorbed. There is an important risk of resonance effects in the cavity between the jaws and the bellows with a potential risk of temperature runaway in the RF fingers and bellow walls. The KEK team should consider the insertion of ferrite slabs in the cavity with active water cooling. The losses would be concentrated in the ferrites rather than in any other delicate component. Very low outgassing ferrite are available from a Japanese company, their outgassing rate can be reduced by thermal treatments in air and then in vacuum.

The proposed RF fingers are quite short and the risk that uncontrolled movements displace them out of the stainless-steel component is not negligible. The KEK team should consider an independent method to measure the position of the jaws, which does not rely on the step motor positioning. At CERN an optical method is proposed for the LHC collimators. This is based on a glass fiber that enters the vacuum system from a feedthrough and conveys an optical signal and is processed outside the ring.

Inconel was chosen as the RF finger material. Cu-Be could be a valid alternative as it has a higher thermal and electrical conductivity.

There are detached stainless steel particles after the long-duration test. The problem was partially solved by silver coating of the Inconel fingers. It should be interesting to coat also the stainless steel part with Rhodium. The coating is generally done by electroplating. The silver-rhodium contact would not generate cold welding by solid solution of the two elements (Ag and Rh are immiscible).

18) Overview of Injector

Considerable progress has been demonstrated on many fronts: a sophisticated drive laser system, a functioning Quasi Traveling Wave (QTW) RF gun, experience making beam using Ir₅Ce and LaB₆ photocathodes, electron beam production and delivery through the injector linac, emittance measurements, RF conditioning of the large aperture S-band positron capture section, upgraded LLRF and timing control for simultaneous feeding of 4 + 1 rings.

But significant challenges related to achieving Super KEKB luminosity remain: operation at higher bunch charge for both electron and positron beams, demanding emittance requirements, tight requirements on monitoring the beam position, and a demanding schedule that requires commissioning of many new components including the positron source and positron damping ring. The earthquake and Super KEKB construction has alerted KEK staff to tunnel motion, 0.1mm/day, comparable to the quadrupole and RF cavity alignment specification.

To achieve Super KEKB luminosity requirement, the staff will pursue a phased approach, beginning with “modest” bunch charge and emittance and working their way to final goals over ~3 years.

19) Injector Commissioning

The new tunnel and transport line to the PF-AR will provide a means for simultaneous top-off, thereby eliminating the twice daily interruption to SuperKEKB physics.

Emittance preservation is key to achieving the SuperKEKB luminosity goal. The linac quadrupoles need to be aligned to about 100 microns to minimize emittance growth at high charge. The observation of tunnel movement at this level is therefore worrisome, because it will be difficult to keep the mechanical alignment of the linac constant for more than a day or two. The KEK staff is considering “girder movers” to keep the quadrupoles and RF-cavities aligned. Alternatively, beam launch angles and offsets can be used to partially compensate the emittance growth. Another possibility is real-time monitoring of emittance and feedback to adjust beam position.

A system to monitor the tunnel motion is being developed.

A fire damaged the cables to the positron source solenoid/flux concentrator. The damage is being repaired, but this has introduced a delay that complicates commissioning. RF conditioning of the Large Aperture S-band capture section is on going. The commissioning schedule was aggressive before this setback. The Committee believes the speaker when he said “there is not enough time for study.”

Drive laser stability issues are a key concern (timing stability, amplitude stability and pointing stability).

5 nC was successfully extracted from the RF gun but only 0.58 nC arrived at the end of linac. Beam loss and emittance degradation seem discouraging. But really, this is quite an accomplishment given the many new devices that were installed and all the work going on in parallel, and the relatively small amount of time devoted to beam commissioning so far.

20) RF Gun and Emittance Preservation

The Disk and Washer gun was used successfully for linac re-commissioning but was not considered to have sufficient RF focusing for the highest bunch charge. The QTW gun has now been completed and is installed in the linac and operating. The new gun has delivered 5.6 nC but not yet with the desired long term stability. The LaB₆ cathode was tested but exhibited quantum efficiency degradation and a prolonged laser cleaning time. Ir₅Ce appears

more promising, showing easier laser cleaning and more stable operation over many hours. Thermal enhancement of quantum efficiency may be an option. Laser pulse pre-heating could produce the desired high temperature but might risk surface fatigue analogous to the RF pulse heating damage in normal conducting cavities. Continuous back heating of a thermally isolated cathode could be an alternative if needed.

The new in-house developed Yb doped laser is working and has been used to commission the QTW gun, but temporal shaping has not yet been implemented. It is believed that longitudinal pulse shaping (square pulse) is required to achieve the needed low energy spread at high bunch charge.

10 nC will be needed for positron production but not at such low emittance. This might be provided by the QTW RF gun but could also be provided by a separate gun with a pulsed dipole magnet to switch into the linac.

Emittance preservation is challenging because of tunnel motion due to ongoing construction activities on the site. Although the elements can be aligned on the girders to better than 0.1mm there has been as much as 0.7 mm ground motion along the linac in only one month. Active movers under the girders may be a solution and these are being evaluated. Injecting off axis and with an angle after the bend may be another alternative. Simulations show that this can compensate for the random errors. In practice correctors after the bend with on-line emittance monitor at end of the linac may allow for real time feedback. An X-band RF dipole diagnostic cavity is being developed.

Remarkable progress has been demonstrated toward developing a very sophisticated drive laser capable of providing mJ pulse energy at the required pulse repetition rates, and at UV wavelengths suitable for illuminating Ir5Ce and LaB6 photocathodes, to create electron bunches with nC bunch charge. But significant challenges remain, in particular related to timing stability, amplitude stability, pointing stability, temporal and spatial pulse shaping, and sufficient output power at the UV wavelengths for the relatively low quantum efficiency of the available photocathodes.

It must be pointed out that the Super KEKB program has multiple photo-guns and therefore requires multiple drive-lasers, but has only one laser group to support them all.

The laser staff is clearly top notch, exhibiting a high level of enthusiasm and competence. However, the QTW laser system is very complex, and with complexity comes risk. The system requirements are so unique that obviously much in-house development is required, but some individual components of the laser system might be available commercially. For example, PriTel sells an actively mode-locked Yb-fiber laser that appears to meet many of your specifications for the laser master oscillator, although with pulse repetition rate ~ 1 GHz. However, it should be reasonably simple to reduce the repetition rate using fiber coupled telecom EO modulator(s). The key beneficial feature of this laser is that it can be easily synchronized to an external RF reference with timing jitter < 1 ps. Just attach an RF signal from the accelerator to a port on the front panel of the device. The laser output from this device could be fed directly to a commercial fiber amplifier to boost power to the Watt level. All of these components could be rack-mounted, with no mirrors to align or clean. Purchasing these components would serve to eliminate some of the free space optical elements, and reduce the complexity of the laser table, improve system reliability and free-up manpower to address other critical laser components not available commercially (e.g., the regenerative amplifier, high power Yb-disk amplifier and frequency doublers).

Another alternative strongly recommended is to consider using a gain switched diode laser to replace the mode-locked Yb-fiber laser master oscillator. Gain switching does not rely on

laser cavity length, and provides a pulse width of ~30ps with excellent timing and amplitude stability. It could also eliminate the pulse stretcher. A diode laser with fiber optic pigtails makes it easy to connect to commercial telecom EO pulse pickers and fiber amplifiers, without loss or alignment concerns.

A worthwhile goal is to eliminate as many free-space optical components as possible.

Just as the SuperKEKB program relies on a phased approach, achieving ultimate success over a period of years, it would be worthwhile to start with as modest a drive laser as possible, and introduce complexity related to pulse shaping over a period of years. Laser problems could seriously hinder Super KEKB commissioning. If possible, pulse shaping should not be implemented until laser instability and reliability issues are resolved. Pulse shaping always results in significant laser power loss, which therefore shifts the problem to the photocathode (not easily solved). Also, perhaps the desired temporal electron bunch shape could be obtained using a linac beamline RF deflector, to remove the Gaussian head and tail from each bunch? Of course, more laser power is needed to address the lost beam.

Photocathode heating (via IR laser, and/or resistive heater applied to the back of the photocathode mount) was discussed as a means to boost photocathode QE. The Committee wonders if continuous heating of the photocathode to 1000C would eventually destroy the photocathode, and if heating would degrade the beam emittance. Certainly, it is a worthwhile goal to boost photocathode QE from mid- 10^{-5} to 10^{-3} , as this would reduce the burden on the drive laser, but photocathode heating might lead to unwanted, unintended ill effects.

21) Positron Source

The positron source for SuperKEKB must ultimately provide a 4 nC positron beam to the LER, a factor of four increase over KEKB. For commissioning, 1 nC will be sufficient. The damping ring (DR) that is needed to reduce the emittance of e⁺ beams is under construction, and will be available during Phase II commissioning in 2016. The QTW RF photogun must ultimately provide 10 nC bunches to the off-axis positron target. Emittance degradation associated with off-axis positron production will be corrected in the damping ring. Other key features include a positron target inside a solenoid field flux concentrator (FC), and a capture section composed of Large Aperture S-band RF cavities (LAS).

The off-axis positron production can introduce significant degradation of yield but this can be improved by a transverse kick and adjusting the incident beam position. There is a beam spoiler screen to protect the beam target. A fire at the solenoid flux concentrator has introduced a ~ 4 month delay in commissioning. Careful RF commissioning of the capture section is underway, but is taking longer than expected due to multipactoring. A doublet focusing system is adopted for lower-emittance beams after the DR.

22) Timing system

We appreciate the clear presentation and overview of the timing system for KEKB. The system is built on a general architecture using Event Generator and Event Receiver functions packaged in VME modules. The system for SuperKEKB is an extension of the KEKB implementation. There are functions to synchronize the timing to the master oscillator (the basic counting rate is 114 MHz) as well as functions to synchronize to the 50 Hz AC main power distribution. All machine functions of RF control, pulsed system control, diagnostics, etc. are controlled through the timing system.

The system is dynamic and uses unique timing programs or sequences to operate the linac and ring functions, and to synchronize the injection needs for 4 different configurations.

Because of the positron source and damping ring, the LINAC is configured in two quasi-independent timing groups.

There has been significant progress in specifying and defining the system needs as well as developing the operational hardware. The original KEKB timing system, which is a less-complex system using EVG/EVR and programmable delay modules, is going to be kept intact as the new system is commissioned. This approach allows incremental addition of new features and some diagnostic capability in comparisons between old and new systems.

The architecture cascades three levels of event generation to satisfy the operation of the damping ring, which must store positrons for cycle times longer than a single linac cycle. For electron acceleration, the operation is straightforward with the event timing controlling the pulsed functions and pulsed diagnostics. By using the cascaded event generators, operating cycles that generate positrons, store them, and then extract them can be designed to inject into arbitrary damping ring buckets (consistent with the rise/fall times of the injection kickers), and then extract, accelerate and inject into arbitrary main ring buckets.

There are two options for a future expansion of the system. The preferred option is to change the phase of the RF in the second half of the Linac. An alternative that was examined is to slowly modulate the phase of the damping ring RF system during the store to position a selected bunch for extraction to fill a particular main ring bucket. This option has only a limited range (± 1 main ring bucket) and was therefore considered as a backup plan. The parameters of the damping ring injection and extraction timing and the store duration must be programmed on each injection cycle for all cases. At present, it is not possible to inject into every LER bucket on each cycle; however it is possible to inject into every bucket within a few pulses. After the upgrade, it will be possible to inject into every LER bucket on each cycle.

The selection of the necessary event timing is a numerically deterministic program, and this coding might be complex enough that the proper computation of the three levels of timing parameters might have quirks that only are revealed for some particular combinations of delays, buckets and configurations. Robust testing of this program over the range of necessary delays and synchronization will be important to avoid having to debug any timing glitches during KEKB commissioning. It may be useful to make a software EVR/EVG simulator, and test the program sequences generated for the various operating cycles over a wide range of necessary parameter space. Having such a simulator may be helpful during commissioning to understand if what is happening in the sequences is something in the hardware, or something in the software that generates the timing programs.

The overall work plan is well underway, and many fundamental choices have been made. There is still significant software development to complete and much hardware to integrate.

We are confident that at a future MAC review there will be presentations on the successful commissioning of the timing system.

23) Status of Linac LLRF Systems

A new digital LLRF system is being developed for the linac RF stations. An RF stability error budget analysis has been performed including contributions from high voltage power supply noise and the RF amplifier chain. Assuming these terms are uncorrelated, the expected RMS energy error is well within the requirement for SuperKEKB. The systems now have to interleave beams for 4 different rings so a large number of parameters have to be updated at 50 Hz. The ensemble will be controlled by a new event generator system. The new ADC

board has been tested and is within spec. A new RF monitoring system has been developed and tested and has been interfaced to EPICS.

8 new RF drive units have already been installed and tested in the linac. All the stations will be operating on the new system by Sept. 2014. Half of the RF monitors will be installed by that time, the remainder planned for 2015.

24) Development of Pulsed Magnets for Injection and Abort Systems

The pulsed magnets system of the KEKB LER will be re-used in phase-I operation. Then, they will be upgraded in phase-II to match the injection parameters of the DR and the target operation current. The prototype of the LER injection septum is designed to have very low field leakage by using a combination of Si-steel sheet in the septa and SUS430 beam pipe in the main ring. However, the amplitude flatness of the excitation field can still be improved. The newly designed pulse power supplies for the septum are underway to improve the stability and availability of the system.

The development of the pulsed magnet system of the HER achieved very good progress. The new injection and abort system of the HER is installed. A betatron injection scheme is adopted as baseline for HER. Two injection kickers are separated by 180° in phase. Time and excitation amplitude jitter of the kickers produce a 1 mm in the bump height. There is a quadrupole inserted between the injection kickers. The tuning of the focusing strength of this QP will affect the bump during injection. As for the main ring abort kickers, the inner surface of the kicker is coated with Cu and cooled by water. During a thermal loading test of the ceramic chamber, the temperature of the kicker chamber increased by $\sim 10^\circ$ with water-cooling of the chamber.

The extraction septum of the damping ring is designed as an out-of-vacuum type, sharing the same vacuum of the ring and transfer line. The Committee is pleased by the progress of pulsed magnet system for injection and abort in the damping ring and main rings.

Recommendations

Setup a solid schedule for the new injection components to be consistent with the DR schedule and meets the Phase II and Phase III milestones.

The proposal to replace the thyatron tube with a solid-state switch is encouraged to reduce the jitter, cost and to improve operation stability.

The leakage field shielding of the prototype septum for HER gave very good results. The leakage field shielding for the rest of the septum should be optimized in a similar way.

25) Normal-Conducting Cavities for MR and DR

11 couplers for the upgraded ARES cavities have been successfully commissioned at 800 kW. Rinsing with ozonated water before baking shortened the conditioning time from 4 weeks to 3. The couplers have extended tips to increase coupling for higher beam current. 10 upgraded couplers will be installed at T=0. All cavity moves between the rings will be completed in 2014 and all 30 MR cavities will be re-commissioned by the end of the year.

The prototype and first damping ring cavities have been tested and exceeded specification. There are clear improvements in the first production cavity that was electropolished. The cavity conditioned more quickly and had less field emission. With the experience of the prototype cavity, the DR cavity No.1 was made with improved performance in frequency accuracy and unloaded quality factor Q_0 , its low and high power test has been performed successfully, with smooth conditioning up to $V_c=0.95\text{MV/cav}$ ($P_{\text{wall}}=210\text{kW}$) without any

performance limit observed. The electropolishing effects, including lower vacuum pressure, lower cavity trip rates and lower radiation during the HPT, are clearly confirmed, and stable operation with $V_c=0.8\text{MV/cav}$ has been demonstrated. The fabrication of DR cavity No.2 is in the final stage passing the low-power test; the HPT is to be conducted in May - June, 2014. This shows that a successful development has been achieved.

The DR cavity No. 1 was assembled with all dampers and was leak tested but was not powered with RF in this configuration. The first opportunity to power the full configuration will be in the DR tunnel. This will be an important test.

26) Superconducting Cavity

Important progress has been made since the last review. Horizontal high-pressure water rinsing of the spare cavity in the cryostat was successful on the second attempt. The coupler and HOM loads were removed for safety and reinstalled successfully. A second cavity was then processed and this was also very successful with a significant improvement in Q and maximum gradient.

Detailed analysis of the HOM power distribution has been performed for the higher beam currents of SuperKEKB. Power into the beam pipe loads is a concern, however simulations show that a significant fraction of the power escapes down the small beam pipe and can be intercepted in the warm regions between cavities. This has the advantage that the SRF cryostats themselves don't have to be modified. A half length prototype SiC small beam pipe load has been made and tested up to 7 kW (equivalent to 14 kW in the full length), but has a higher than optimal temperature rise. A second version is being developed with increased cooling. This should alleviate the heating concern of the existing beam pipe absorbers. The increased beam current will require additional power to be supplied by the main cavity power couplers. The window design has been proven to much higher power levels, however additional conditioning on the cavity may be needed.

27) LLRF development for MR and DR

The LLRF functions for SuperKEKB are implemented in a digital architecture that uses uTCA modules with FPGA based signal processing functions and IOC functions, plus necessary RF LO and processing hardware to mix signals from the 509 MHz fundamental frequency to a 10.9 MHz IF processing frequency. The processing uses an I/Q formalism, with digital PID control loops to regulate the cavity fields. The same basic modules are used for both rings, and for both the ARES and superconducting RF cavity systems. The systems include monitor functions and cavity tuning control loops.

The team has made impressive progress in the past year. The investigation of the gap transient effect is important, and the team has concluded that "except for the leading part of the bunch train" the synchronous phase variations in the two rings is insignificant.

Because of the high beta interaction region, variations in synchronous phase between the rings may have an impact on luminosity during the mismatched transient, as well a shift in the luminous region. The presentation suggests more work is being done to clarify the significance of this effect for bunches immediately following the gap; the Committee agrees it is necessary.

Similarly, the gap transients in the cavity amplitude may also need study to understand if they may cause saturation of the klystron drive during the gap, as the I/Q control loops will generate error signals to try to keep the cavity fields at the amplitude set points.

The studies of the closed loop transfer functions and disturbance rejection are very significant and we compliment the team for this work.

The high power RF system uses a variation in the klystron HV power supply to accommodate output power demand variation, and the designers have included a phase compensation regulation loop to keep the insertion phase across the klystron constant. A demonstration of this loop was shown using a 100W amplifier in place of the klystron, with a slow phase modulation in series with the amplifier drive. These tests show excellent regulation of the phase loop. However, the actual klystron will change its' forward gain with variations in HV power supply, so the PID loop gains also change with operating point unless the regulator controls the overall loop gain. From the slides it isn't clear if the klystron loop only corrects phase variations (the "KLY-PLL rotation" matrix seen in slide 8) but the system will be tested with a high power klystron soon.

The system includes a path to inject a beam-derived mode -1 error signal, it isn't clear from the presentation if this signal is injected into all klystrons or if one or a subset of the RF stations are used to control the mode -1 instability.

There has been tremendous progress and the work is impressive. We look forward to seeing some high power commissioning results at the next MAC review.

28) Controls

The Control system for SuperKEKB is EPICS based, and in the past year there has been significant work upgrading the network infrastructure and fiber optic distribution systems. This work increases the bandwidth of the communications in addition to providing redundancy and better reliability. Significant work has gone into refurbishing many aspects of the computing systems and preparing for more complex control, monitoring of the accelerator complex and communications with the BELLE detector.

As part of the upgrade many control functions originally packaged in VME or CAMAC are migrating to commercial IOC or uTCA form. This use of commercial standards is very attractive economically but the lifetime of commercial products can be very short compared to accelerator facilities. As in past reviews we suggest that the team consider the necessary investment in spares that will be needed in the operating years, as direct replacements for some functions will not be so easily available.

The presentation showed a power supply control board PSICM that is going to be widely used, roughly 3000 boards. This is an excellent implementation with useful upgraded features. We wonder if there is a plan to have the vendor doing fabrication test these boards (does the board design have loopback and self-test functions?), so that the team at KEK does not have to find manufacturing faults or do testing of so many discrete systems.

The plans for the monitoring and fault file recording are well defined and these archiving functions will be very useful, and important as the machine moves beyond commissioning into the operational years.

29) Ring Commissioning

The ring commissioning plan including the LER, HER and Positron Damping Ring was covered in detail. The plan covers Phases 0, 1, 2, and 3 starting from the beginning of beam operation, and ends in Phase 3 with the detector receiving data at a luminosity of $1 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$. Commissioning includes equipment checkout, beam transport, beam storage, lattice corrections, high current operation, and finally detector compatibility.

According to the master schedule the commissioning Phase 0 started in September 2013 and will continue until about December 2014. This phase consists of the commissioning of the linac in parallel to completing the SuperKEKB construction and to preparing software for the ring commissioning.

Commissioning Phase 1, planned from January to June 2015, comprises linac tuning (if necessary), basic commissioning of machine (1.5 months), vacuum scrubbing (more than three months, of which at least one month with beam currents of 0.5-1 A), damping ring commissioning (starting from May 2015), detector beam background studies, some optics tuning (with smooth beta functions), and studies of beam instability (FII, e-cloud).

The damping ring installation will start in April 2014. The plan for commissioning the damping ring in one month, from May to June 2015, looks aggressive, in particular as there is no dedicated damping-ring team for the commissioning.

Special beam monitors available during Phase 1 include the XRM for emittance tuning, streak camera for bunch length studies, and 110 turn-by-turn BPMs. A measurement of the beam energy spread for microwave instability studies is not easily available but would be valuable for diagnostic analysis.

Commissioning Phase 2 extends from February to June 2016, comprises optics tuning with tentative target values four times the nominal β^*x and eight times the nominal β^*y , optics tuning with QCS and BELLE II solenoid, detector beam background, tests of continuous injection, increase of beam currents (instability, RF power, vacuum issues), beam collision tuning, collision tuning, and finally luminosity tuning. The target luminosity for Phase 2 is $1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$.

Phase 3 will start from October 2016 includes optics tuning towards the design IP beta functions and low emittance tuning, more detector beam background studies (establishment of continuous injection), increase of beam currents from 1 A to the design values, and luminosity tuning. The first important milestone for Phase 3 is achieving a luminosity of $1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$. The major goals for this period are 1) to develop methods to make the beam lifetimes as long as possible and 2) develop techniques to correct the optics including the effects of the beam-beam interaction.

Beam monitors in Phases 2 and 3 includes 270 turn-by-turns, gated turn-by-turn BPM, BPM orbit interlocks, beamsstrahlung monitors, a BPM for IP orbit feedback, and a fast luminosity monitor.

Phase 1 still uses the old LER injection/abort system. For this reason the LER current must be kept low to protect the abort window, or alternatively the emittance must be enlarged for scrubbing with high current. An optical scheme for controlling any increase in the emittances has been developed.

An ICFA workshop on SuperKEKB commissioning was held last November with about 70 attendees. Numerous critical issues were identified at the workshop.

Recommendations

In order to complete the DR commissioning during a one-month period, a precise commissioning plan needs to be prepared with detailed procedures and decision trees and sufficient commissioning staff identified.

Efforts should be made to involve collaborators (e.g. from SLAC, CERN, light sources and/or KEK-ATF) in the commissioning of all three SuperKEKB rings (damping ring, LER, HER).

During Phase 2 an option to run fewer bunches but with more charge per bunch should be investigated to get an early look at future beam instabilities.

Optics and dynamic aperture corrections and beam lifetime involving the beam-beam effect should receive additional study as the combination is problematic at present.

Appendix A

KEKB Accelerator Review Committee Members

Andrew Hutton, Chair	JLab
Paolo Chiggiato	CERN
John Fox	SLAC
Stuart Henderson	FNAL (unable to attend)
Gwo-Huei Luo	NSRRC
Won Namkung	POSTECH
Evgeny Perevedentsev	BINP
Matt Poelker	JLab
Bob Rimmer	JLab
Kem Robinson	LBNL (unable to attend)
John Seeman	SLAC
Zhao Zhentang	SINAP
Frank Zimmermann	CERN
Katsunobu Oide	KEK, Ex Officio Member
Kazunori Akai	KEK, Secretary, Accelerator
Kazuro Furukawa	KEK, Secretary, Accelerator
Haruyo Koiso	KEK, Secretary, Accelerator

Appendix B Agenda of the 18th KEKB Accelerator Review Committee

March 3 (Monday)		
08:30 - 09:00	Executive Session	
09:00 - 09:15	KEK Roadmap	Y. Okada
09:15 - 09:55	Overview of Ring Construction Status and Schedule	K. Akai.
09:55 - 10:25	Belle II physics, schedule and construction status	S. Tanaka
10:25 - 10:45	Beam dynamics issues	K. Ohmi
10:45 - 11:05	Impedance Issues	D. Zhou
11:05 - 11:50	Optics Issues	Y. Ohnishi
11:50 - 12:20	IR overview	K. Kanazawa
13:30 - 14:20	Final focus magnets	N. Ohuchi
14:20 - 14:40	Beam background	H. Nakayama
14:40 - 15:00	Collision Feedback	T. Oki
15:00 - 15:30	Magnets and power supplies	H. Inuma
15:50 - 16:10	Magnet support	H. Yamaoka
16:10 - 16:35	BPM and bunch feedback system	M. Tobiyaama
16:35 - 17:00	Photon monitors and loss monitor	J. Flanagan
17:00 - 17:15	Vacuum construction status	Y. Suetsugu
17:15 - 17:30	TiN coating and baking	K. Shibata
17:30 - 17:45	Collimator	T. Ishibashi
March 4 (Tuesday)		
08:30 - 09:00	Executive session	
09:00 - 09:10	Overview of Injector	K. Furukawa
09:10 - 09:50	Injector commissioning	M. Satoh
09:50 - 10:30	RF gun and emittance preservation	M. Yoshida
10:50 - 11:20	Positron Source	T. Kamitani
11:20 - 11:40	Timing system	H. Kaji
11:40 - 12:00	LLRF development	T. Miura
13:10 - 13:35	Development of pulse magnets for injection and abort system	T. Mori
13:35 - 13:55	Normal-conducting cavities for MR and DR	T. Abe
13:55 - 14:10	Superconducting cavity	Y. Morita
14:10 - 14:30	Status of LLRF system	N. Iida
14:50 - 15:20	Control	M. Iwasaki
15:20 - 15:40	Ring Commissioning	Y. Funakoshi
March 5 (Wednesday)		
08:30 - 12:00	Executive Session / Report Writing	
14:00 - 15:00	Close-out	

